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May 19, 2000

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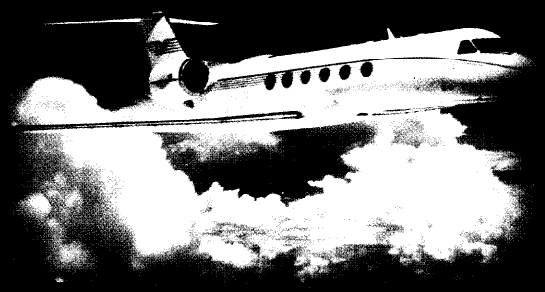
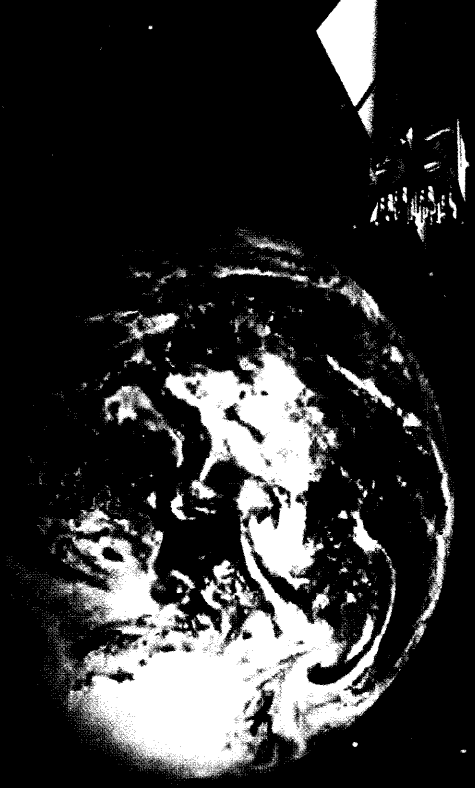
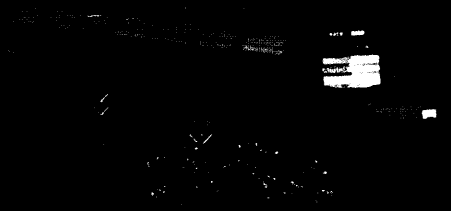
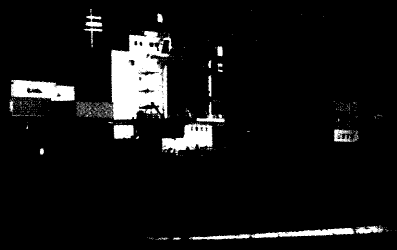
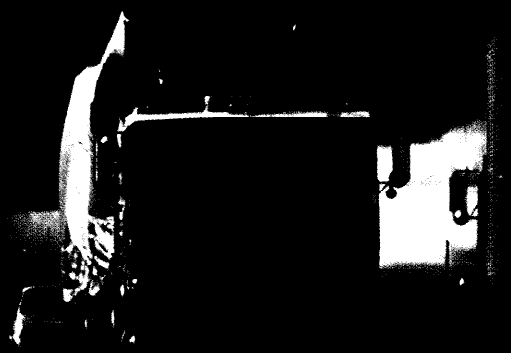










NATIONAL Civilian GPS SERVICES

Global Positioning System (GPS)
GPS Augmentations
GPS Modernization

U.S. Department of Transportation

THE SECRETARY OF TRANSPORTATION

WASHINGTON, D.C. 20590

March 21, 2000

The Department of Transportation (DOT) has long recognized the potential of satellite navigation to improve both the safety and efficiency of the national transportation infrastructure. The Global Positioning System (GPS) is an excellent example of innovation and technology enhancing the quality of life of our citizens. Under our concept of ONE DOT, we are implementing GPS-based systems for the land, air, and maritime transportation of the nation. These systems embody the vision of the DOT to ensure a transportation system that is international in reach, intermodal in form, intelligent in character, inclusive in service, and innovative in scope.

The United States is modernizing the GPS through a program that will improve its civilian service in the new century and the new millennium. A number of DOT agencies are implementing "augmentation" systems that will improve the current civilian GPS service. Aviation augmentation systems will support all phases of flight and enable the Department's "Free Flight" and "Safer Skies" initiatives to improve the safety and efficiency of our National Airspace System. The surface-transportation augmentation system will serve both maritime and land travel nationwide and support both the Department's Marine Transportation System and its Positive Train Control (PTC) initiative. PTC will enable the nation's railroads to dramatically reduce the risk of train collisions and is one of the National Transportation Safety Board's "Most Wanted" safety initiatives.

Many state agencies are key partners in this process and recognize the benefits of augmented GPS in areas such as snowplow guidance, inventory management, pavement-condition mapping, land-use management, geographic information systems, and traffic databases. Local governments also benefit in areas such as emergency response (e.g., police, firefighters, and rescue units), vehicle location, and fleet management.

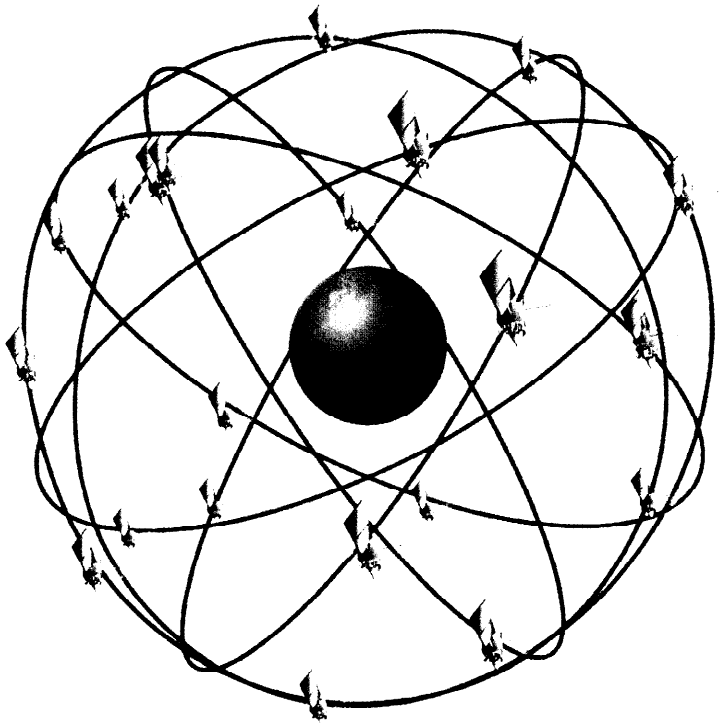
We are excited about the opportunities that the GPS, its augmentations, and its modernization will offer our states, our nation, and the world. In the future, this innovative technology will empower a host of transportation, commercial, and scientific applications benefiting mankind worldwide.

Sincerely,

Rodney E. Slater

The Global Positioning System (GPS)

The Global Positioning System (GPS) is a fully operational, worldwide, all-weather, satellite-based navigation system originally developed in the 1970's. The GPS Standard Positioning Service (SPS) provides civilian users a horizontal position accurate to within 300 feet and a vertical position accurate to within 500 feet. Although the GPS is able to deliver much better service than this, the level of SPS accuracy is degraded in the interest of national security by the use of "selective availability" (SA). There are also other reasons for the decreased accuracy of the SPS, including "atmospheric errors" introduced by nature as the satellite signals travel through the earth's atmosphere.



24 operational GPS satellites

Orbit about 12,500 miles above the earth in 6 orbital planes.

Each satellite completes one orbit every 12 hours.

Figure 1: The GPS "Constellation"

How GPS Works

The Global Positioning System (GPS) works in the following way. The fully operational GPS constellation consists of a minimum of 24 satellites orbiting about 12,500 miles above the surface of the earth. Each satellite continuously transmits radio signals giving the satellite's location and the precise time at which the signal was sent. The GPS user equipment receives these signals, measures relative arrival times, and from these computes the position of the user. By receiving the signals from at least 4 satellites, a GPS receiver can determine its three-dimensional geographic coordinates and precise time.

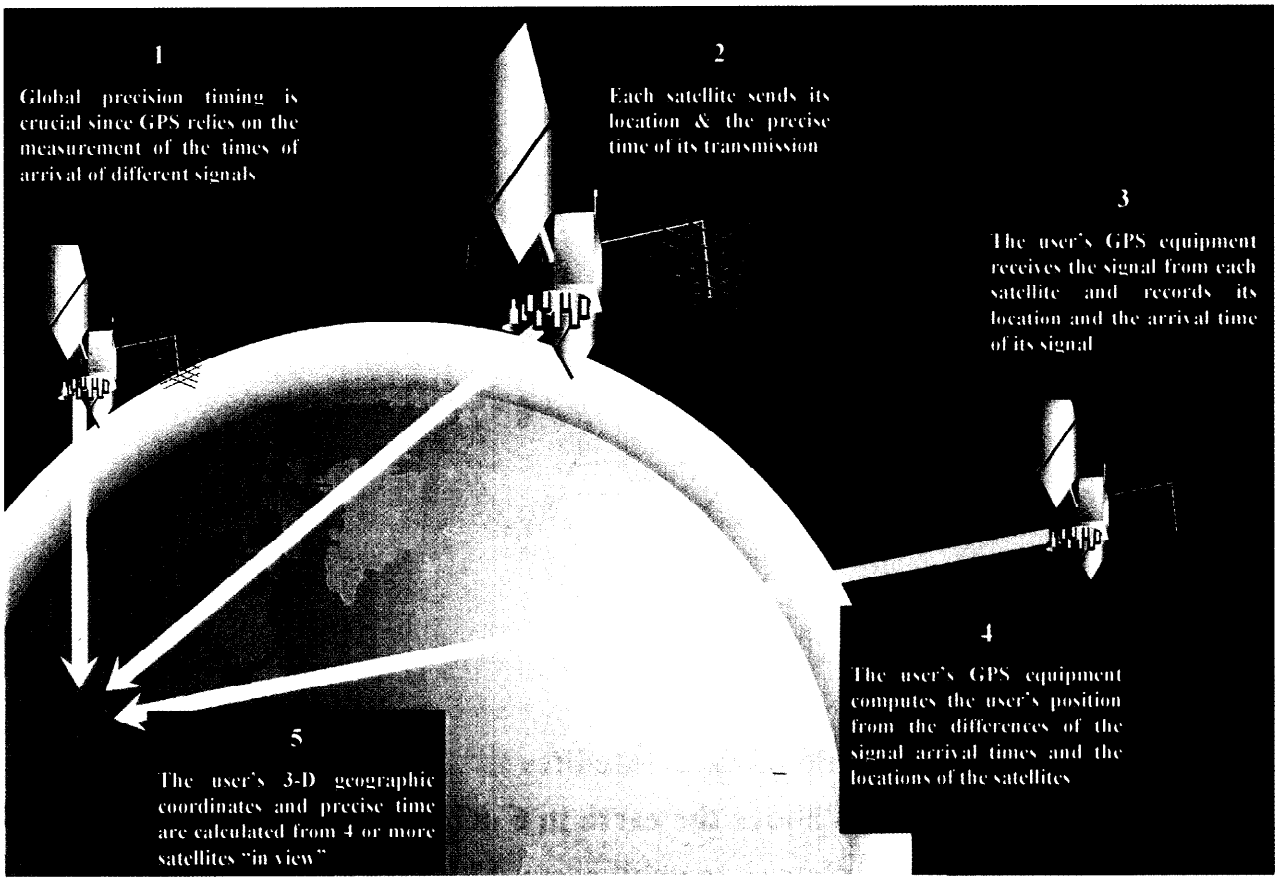


Figure 2: Theory of GPS Positioning

U.S. GPS Policy

In 1996, the President provided U.S. Global Positioning System (GPS) policy in Presidential Decision Directive NSTC-6:

- GPS is a dual-use system (military & civilian)
- GPS promotes safety and efficiency in transportation
- GPS supports both national and international interests
- GPS is provided free of direct user fees
- GPS is managed by the Interagency GPS Executive Board (IGEB)
- The IGEB is jointly chaired by the Departments of Transportation and Defense (DOT and DoD)
- DOT is the lead agency for all Federal civil GPS matters

In 1997, the intent of Congress for GPS was reflected in the National Defense Authorization Act for Fiscal Year 1998:

- GPS contributes to safety and efficiency of international transportation
- GPS has essential civil, commercial, and scientific uses
- GPS is operated for military and civilian purposes
- DOT coordinates GPS augmentations in support of transportation

Figure 3: The agencies of the Interagency GPS Executive Board (IGEB)

Transportation Requirements

For many critical safety-of-life transportation applications, the Global Positioning System (GPS) service alone may not meet the requirements of:

- ***Integrity*** (the ability of a system to provide timely warnings to users when the system should not be used for navigation),
- ***Accuracy*** (the difference between the GPS-measured position at any given time and the actual or true position), and
- ***Availability*** (the ability of a system to be used for navigation when and where it is needed by the users).

	Transportation Application	Integrity	Availability	Accuracy
Maritime	Ocean transit	Yes	Yes	Yes
	Coastal navigation	Yes	Yes	Yes
	Inland waterway	No	No	No
	Harbor entrance & approach	No	No	No
Land	Highway navigation	Yes	Yes	Yes
	Emergency Response	Yes	Yes	Yes
	Transit vehicle management	No	No	No
	Railroad train control	No	No	No
Aviation	Oceanic en route	Yes	Yes	Yes
	Domestic en route	No	No	Yes
	Non-precision approaches	No	No	Yes
	Precision approaches	No	No	No

Requirements can be met by GPS alone — Yes

Requirements cannot be met by GPS alone — No

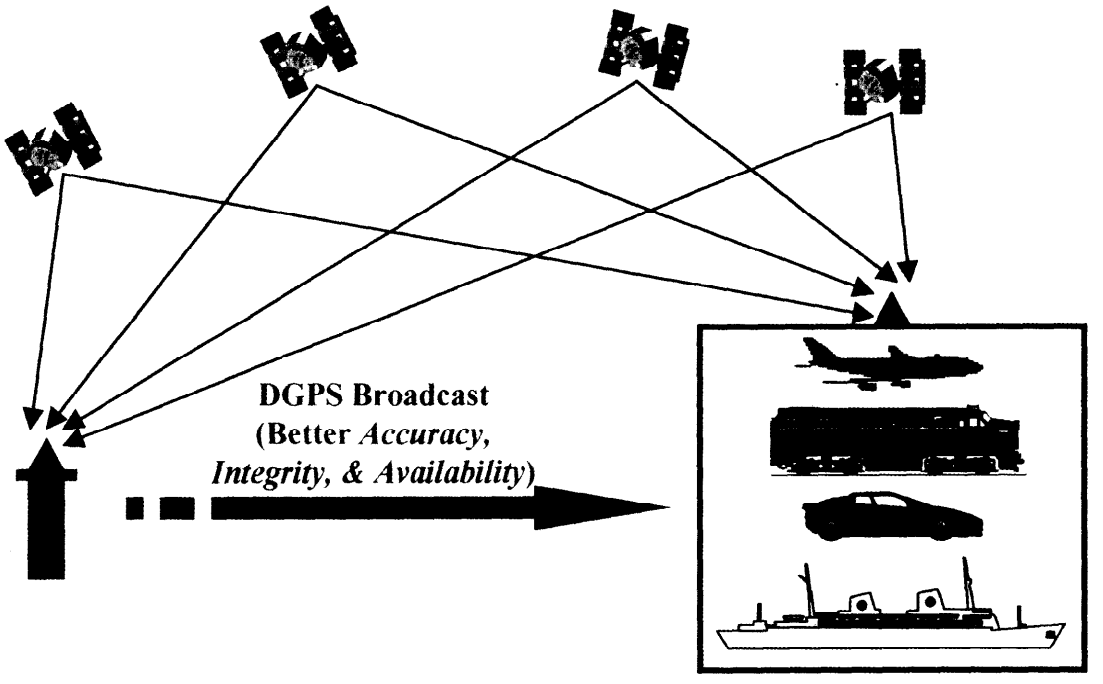
Note: The above generalization does not hold true for some specific applications within each category. For example, non-precision approaches using GPS with Receiver Autonomous Integrity Monitoring (RAIM) are permitted under certain favorable satellite geometries.

Figure 4: Ability of the current GPS alone to meet transportation requirements

Differential GPS (DGPS)

For satellite navigation to meet all the requirements of civilian transportation, the Department of Transportation (DOT) is implementing Global Positioning System (GPS) augmentations based on a technique known as "differential" GPS (DGPS).

A DGPS reference station continuously monitors the GPS signals. Since the position of the reference station has been precisely surveyed, the errors in the satellite signals can be calculated and corrections broadcast to users in the area. The user's DGPS receiver applies the correction message to improve the ***accuracy*** of its own position. The DGPS broadcast may also include ***integrity*** warnings for any satellite signals that should not be used. Additionally, the DGPS service can broadcast a GPS-like signal to improve the ***accuracy*** and ***availability*** of GPS services.



DGPS Reference Station

1. Knows its position accurately,
2. Receives GPS signals,
3. Calculates GPS errors,
4. Broadcasts the differential message.

DGPS Users

1. Receive GPS signals,
2. Receive the differential message,
3. Correct the GPS information,
4. Know their position accurately & also the condition of the GPS service.

Figure 5: The "differential" GPS (DGPS) technique

Improved Accuracy of DGPS

This demonstration illustrates the improved accuracy that differential Global Positioning System (DGPS) services offer the civilian user of satellite navigation. In this case, a user had a receiver able to calculate its position from the GPS satellite signals alone. In addition, this receiver could correct its GPS position using the DGPS broadcast from a Coast Guard DGPS reference station 125 miles away.

With this receiver, the user "navigated" a tennis court:

- The **blue** line was calculated using GPS alone while the user stood stationary in the center of the tennis court,
- The **red** line was traced by GPS alone as the user walked along the lines of the tennis court,
- The **green** line was calculated by DGPS as the user walked along the lines of the tennis court.

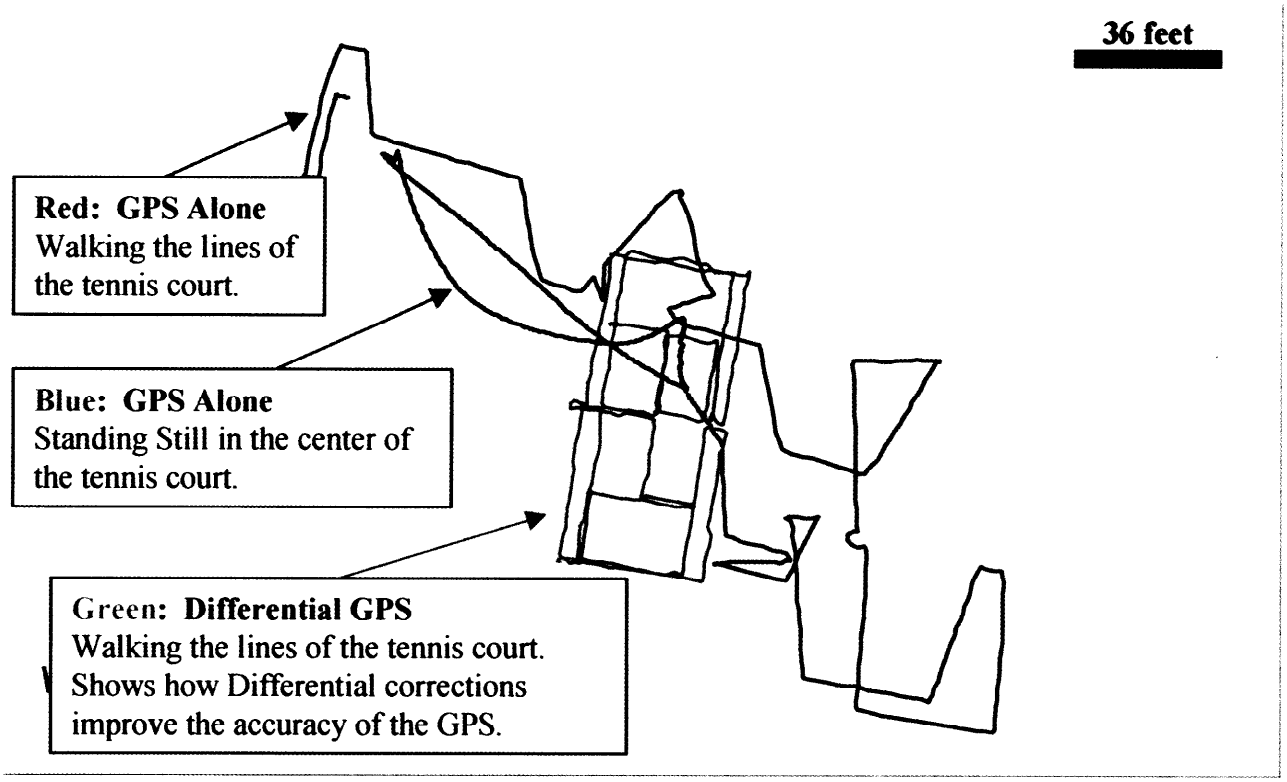


Figure 6: Demonstration of the improved accuracy of DGPS

GPS Augmentation Programs

Together, all of the following Department of Transportation Global Positioning System (GPS) augmentation systems meet the requirements of transportation – maritime, land, and aviation – and at a lower cost than other alternatives.

- **Nationwide Differential Global Positioning System (NDGPS)** for surface transportation (maritime and land),
- **Wide Area Augmentation System (WAAS)** for aviation en-route, nonprecision approach, and the least stringent category of precision approach,
- **Local Area Augmentation System (LAAS)** for all categories of aviation precision approach, landing, and surface operations within LAAS coverage.

	Transportation Application	Integrity	Availability	Accuracy
Maritime	Ocean transit	GPS	GPS	GPS
	Coastal navigation	GPS	GPS	GPS
	Inland waterway	NDGPS	NDGPS	NDGPS
	Harbor entrance & approach	NDGPS	NDGPS	NDGPS
Land	Highway navigation	GPS	GPS	GPS
	Emergency Response	GPS	GPS	GPS
	Transit vehicle management	NDGPS	NDGPS	NDGPS
	Railroad train control	NDGPS	NDGPS	NDGPS
Aviation	Oceanic en route	GPS	GPS	GPS
	Domestic en route	WAAS	WAAS	GPS
	Non-precision approaches	WAAS	WAAS	GPS
	Precision approaches	WAAS/LAAS	WAAS/LAAS	WAAS/LAAS

Requirements can be met by GPS alone

Requirements are met by GPS augmentations

Note: The above generalization does not hold true for some specific applications within each category. For example, non-precision approaches using GPS with Receiver Autonomous Integrity Monitoring (RAIM) are permitted under certain favorable satellite geometries.

Figure 7: Ability of GPS augmentation systems to meet transportation requirements

Surface GPS Augmentations

The Nationwide Differential Global Positioning System (NDGPS) is being implemented for surface transportation (maritime and land). Current coverage consists mostly of the Coast Guard's Maritime DGPS Service, which is now fully operational and an important part of the infrastructure supporting the Department's Marine Transportation System. Over thirty foreign countries also recognize the value of DGPS and have implemented surface DGPS services conforming to the Coast Guard standard.

The Department is expanding the Coast Guard service nationwide for land transportation, primarily to support Positive Train Control (PTC), one of the National Transportation Safety Board's "Most Wanted" safety initiatives. The stringent availability requirements of PTC will be met when NDGPS provides double coverage of the DGPS broadcast to the nation's rail infrastructure.

Many state agencies are also participating since they recognize the benefits of NDGPS in areas like snowplow guidance, asset inventory, land-use management, pavement-condition mapping, geographic information systems, and traffic databases. Local governments also benefit from improved emergency response (police, firefighters, and rescue units), vehicle location, and fleet management.

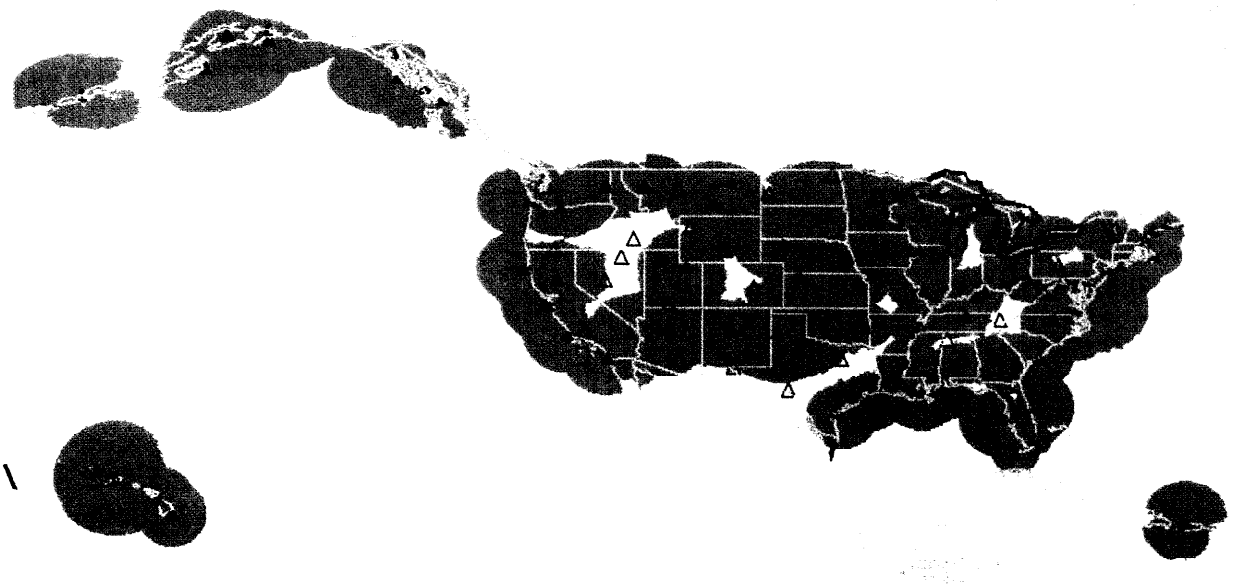
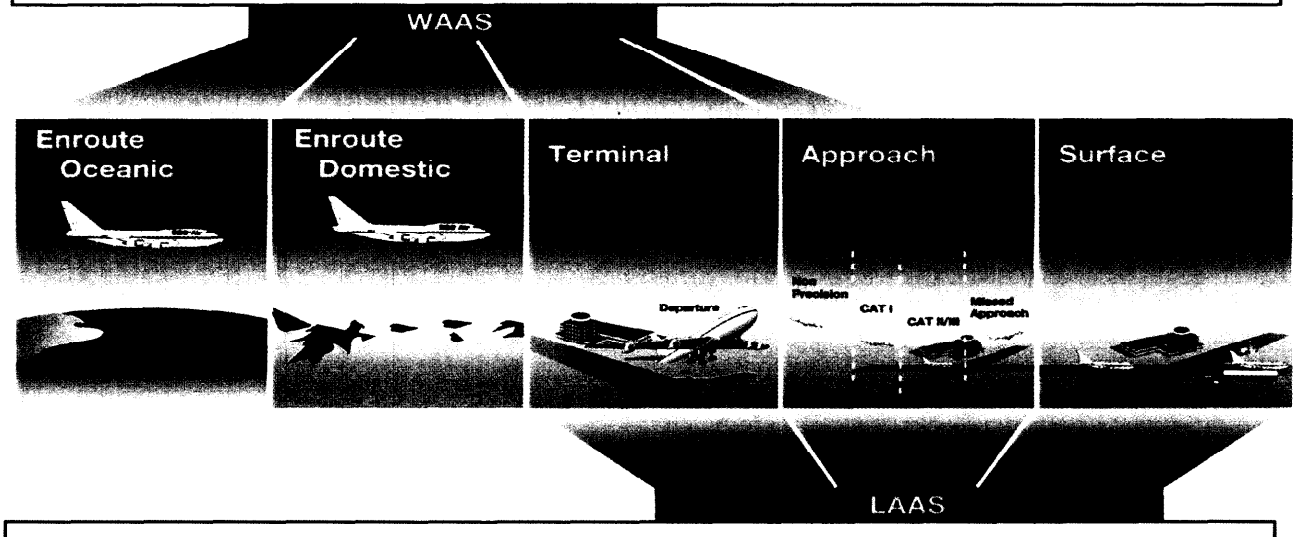


Figure 8: NDGPS coverage by December 2000 (mostly single coverage)

Aviation GPS Augmentations

The Federal Aviation Administration (FAA) is implementing Global Positioning System (GPS) augmentation systems for aviation. Together, the Wide Area Augmentation System (WAAS) and the Local Area Augmentation System (LAAS) will support all phases of flight. They will enable the FAA's "Free Flight" and "Safer Skies" initiatives to improve the safety and efficiency of the National Airspace System.

The Wide Area Augmentation System (WAAS) will provide guidance for enroute flight, terminal, and approach operations. WAAS sends differential correction and integrity messages to aircraft via geostationary earth-orbit (GEO) satellites at the same frequencies as the GPS. In addition to the differential corrections, the WAAS signals provide an additional ranging source for increased accuracy and availability.



The Local Area Augmentation System (LAAS) will meet the guidance requirements for the more stringent approach and surface operations in all weather conditions. The LAAS is intended to complement the WAAS and function together to supply users with seamless satellite-based navigation for all phases of flight. In practical terms, this means that at locations where the WAAS is unable to meet existing navigation and landing requirements, such as availability and accuracy, the LAAS will be used to fulfill these requirements.

Figure 9: Aviation GPS augmentations for all phases of flight

GPS Modernization Program

Led by the Department of Transportation (DOT), the civilian agencies of the federal government are working with the Department of Defense (DoD) to add two civilian signals to future Global Positioning System (GPS) satellites as a part of the GPS Modernization Program. The future GPS will have a total of three civilian GPS signals – one each in the L1, L2, and L5 frequency bands. Two of these bands (L1 and L5) are protected for radionavigation for transportation including aviation, and the other (L2) will be available for non-aviation civilian uses. These new civilian GPS signals will be in addition to the existing and new military signals being implemented by the DoD for national-security purposes.

When all three civilian GPS signals are broadcast from a sufficient number of satellites, the accuracy of the GPS will approach the accuracy now only possible using differential GPS (DGPS) – and the improved service will be ***worldwide***, not only where DGPS service exists. The modernized GPS will also be more resistant to interference since civilian users will be provided with three signals.

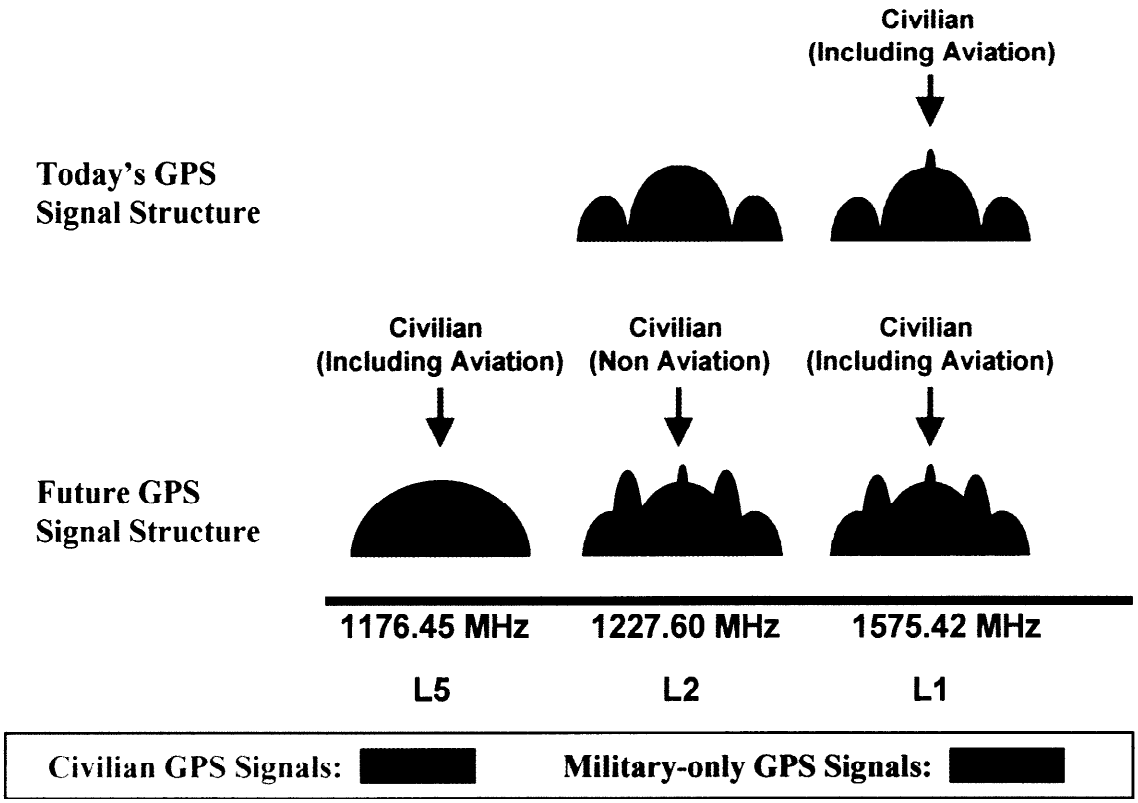


Figure 10: The improved civilian capability of the modernized GPS

GPS in the Future

The two major reasons for the accuracy degradation experienced by the civilian users of the Global Positioning System (GPS) are: (1) **Selective Availability (SA)**, which is introduced by the Department of Defense for national-security reasons, and (2) **atmospheric errors** introduced as the signals pass through the atmosphere while traveling from the satellites to the user.

- By 2006, Selective Availability will be discontinued as directed by the President, thereby greatly enhancing the Standard Positioning Service for many civilian applications. The ensuing level of service still will not meet transportation requirements, and the need for GPS augmentations will remain.
- In the 2010 – 2015 timeframe, additional civilian GPS signals will allow the user's receiver to greatly reduce atmospheric errors with signal-processing techniques and give civilian users added resistance to interference. With more than one signal, the accuracy of the GPS will meet many of the transportation needs for accuracy, and allow reduced augmentation systems to meet the needs for integrity and availability. Two of these signals will be in a frequency band protected for aeronautical radionavigation services.

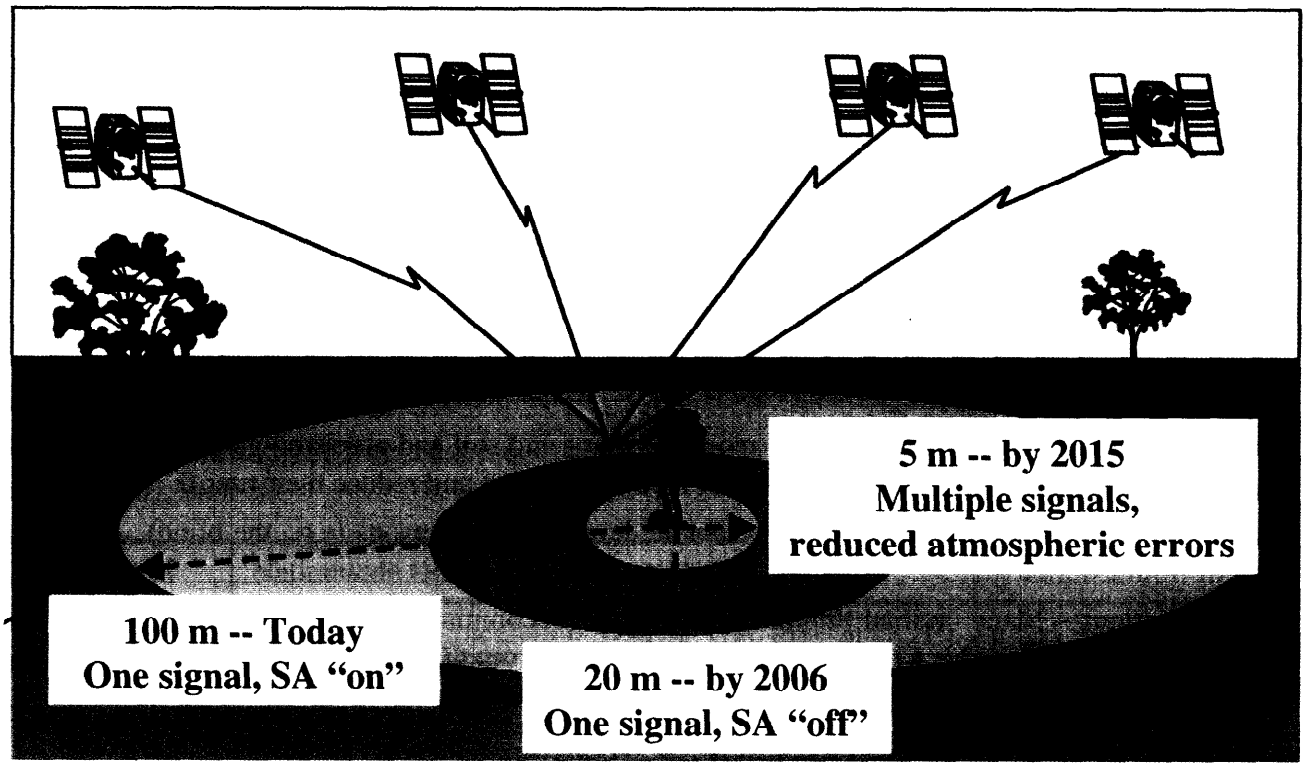


Figure 11: The improved accuracy of GPS in the future

Value of Civilian GPS Services

The augmented and modernized GPS will enhance many civilian uses, such as:

- Positive Train Control (PTC) – The NDGPS will serve the location determination system for PTC, which is one of the National Transportation Safety Board's "Most Wanted" initiatives.
- Free Flight and Safer Skies – WAAS and LAAS will help reduce the domestic accident rate. The new civilian L5 signal will improve the robustness of WAAS and LAAS and improve international safety by facilitating the introduction of precision approaches worldwide.
- Marine Transportation System – The Maritime DGPS Service is part of the MTS infrastructure binding the nation's waterways and ports to railroads, roadways, pipelines, etc.
- Intelligent Transportation Systems (ITS) – NDGPS enables better in-vehicle navigation and automated vehicle location for vehicle guidance and fleet management of taxis, buses, etc.
- Emergency response – Police, fire, ambulance, and rescue coordinators will be able to cut response time and save lives and property using computer-aided dispatching.
- Mayday systems – When a vehicle's airbag deploys, the accurate vehicle location is automatically broadcast, emergency vehicles are notified, and other vehicles are alerted.
- Asset management – NDGPS helps locate assets, such as fire hydrants, signs, and other infrastructure components, even in low or zero visibility such as at night or in severe weather. Snowplows can use DGPS for precision guidance even during whiteout conditions.
- Charting, mapping, and surveying – NDGPS stations are integrated into the Continuously Operating Reference Stations (CORS) network for centimeter-level accuracy for surveying.
- Environmental protection – Accurate location will improve community efforts to locate, contain, and monitor contaminated sites and coordinate cleanup efforts.
- Weather forecasting – NDGPS stations are integrated into the GPS Integrated Precipitable Water Vapor System for improved prediction of severe weather such as tornadoes.
- Environmental protection – Accurate location will improve community efforts to locate and monitor contaminated sites and coordinate cleanup efforts.
- Commercial fishing – The repeatable accuracy of DGPS allows fishermen to return to previous locations to retrieve their gear and catch.
- Precision farming – DGPS allows accurate mapping of crops and soil and precision guidance of vehicles applying chemicals to lower the cost of their application and reduce their runoff.
- Human services – Personal navigation systems can be developed for persons (e.g., the blind) who benefit from external guidance.
- Telecommunications – Many civilian timing uses, such as telecommunications that use GPS for synchronization, will receive a more precise timing service from the modernized GPS.

Frequently Asked Questions

Question: Are these civilian GPS programs important to the Administration?

Answer: Yes. The Vice President announced the new GPS modernization initiative on January 25, 1999. This announcement highlighted the benefits of the second and third civilian GPS signals. In addition, Presidential Decision Directive NSTC-6, March 28, 1996, states: "*The Department of Transportation will serve as the lead agency within the U.S. Government for all Federal civil GPS matters, develop and implement U.S. Government augmentations to the basic GPS for transportation applications, ... coordinate U.S. Government-provided GPS civil augmentation systems to minimize cost and duplication of effort.*"

Question: What are the benefits of these national programs to citizens, state agencies, and businesses?

Answer: Transportation safety and efficiency are every-day concerns of citizens everywhere. The DOT programs will help improve transportation safety and efficiency for all modes of travel and help reduce congestion. In addition, there are many other civilian community functions that need the increased accuracy of the DOT programs. These programs, while national in scope, are also local in focus. As soon as the DOT augmentation services are operationally capable, every state and locality will be able to use them to improve functions such as emergency response, mapping, surveying, recreation, inventory management, automatic vehicle location, environmental management, etc.

Question: What is needed to complete these programs?

Answer: All of these programs are dependent upon appropriations from Congress. The funding requested by the President is necessary to achieve the timely implementation that will allow the nation to benefit. The civilian community is anxiously awaiting these services even now. Reduced funding impacts the perceptions of the Congress and the public regarding the U.S. Government's commitment to providing civilian GPS services on time. In the case of improvements to the GPS itself, the timing of the satellite modifications is tied to the schedules of the Department of Defense (DoD) GPS Modernization Program. The DoD is working diligently and quickly to improve the military capabilities of the GPS for national security, and the civilian improvements cannot fall behind lest they fall out altogether.

The table below summarizes the requests for civilian GPS services in the President's Fiscal Year 2001 Budget:

$18.7 M	Nationwide Differential GPS (NDGPS) – in DOT's Budget Request
$111.0 M	Wide Area Augmentation System (WAAS) – in DOT's Budget Request
$9.3 M	Local Area Augmentation System (LAAS) – in DOT's Budget Request
$66.3 M	Civilian GPS Modernization (L2/L5) – in DoD's Budget Request (for DOT)

Frequently Asked Questions

Question: There seem to be many different programs all doing essentially the same thing. Are these systems redundant?

Answer: No. The various GPS augmentations are optimized for the specific operating environments of the respective transportation users. These are aviation, land, and sea. The three augmentations are designed for these three environments and for the specific safety requirements of each mode. The WAAS broadcasts come from a geostationary earth-orbit satellite and include integrity information, differential corrections, and additional ranging information for essential aircraft altitude determination and increased availability. Eventually, the WAAS will replace many ground-based navigation aids. The LAAS replaces or enhances instrument landing systems for an airport to support takeoff and landing in extreme weather conditions. The NDGPS broadcasts are not blocked by surface terrain features (buildings, hills, foliage, etc) as WAAS signals might be. It is true that surface users will be able to use aviation services in certain circumstances and vice versa; however, in safety-of-life applications such as transportation, full availability is essential and any redundancy can provide increased system availability and improved safety.

Question: Do we need to modernize the GPS if differential GPS meets the need?

Answer: Yes. The civilian improvements to the GPS itself will benefit American travelers worldwide and open new opportunities – but not before the operational capability is achieved some time in the next decade. In addition, three separate civilian GPS signals will give the user resistance to interference and improved availability of the service. In contrast, the DGPS requires a network of land reference stations and only serves users in its coverage area. Having only one civilian GPS signal increases a user's vulnerability to interference.

Question: What will happen to the GPS augmentations after GPS is modernized?

Answer: When the new civilian GPS signals are available in the second decade of the 21st Century, the accuracy of the modernized civilian GPS will meet the needs of many transportation uses. This should allow a reduction in the GPS-augmentation infrastructure, though not its elimination. Augmentations will still be necessary to satisfy accuracy requirements for some applications, as well as integrity and availability requirements.

Question: Are all the different systems integrated? That is, will a user be able to use all the systems together with the same equipment, or will the equipment be system-dependent?

Answer: When all of the new civilian GPS services are available the GPS manufacturers will be able to improve the degree of integration. However, since user equipment is designed for very different applications, there will remain a need for specialized equipment. For example, the requirements of surveying and aviation navigation are significantly different and would result in individual differential GPS receiver designs. In the future, the additional civilian GPS signals will help in this area, increasing the number of applications that a single receiver design will be able to serve.

Frequently Asked Questions

Question: Are federal agencies working together to avoid redundant systems and to save costs?

Answer: Yes. The services that will be available from the DOT programs are in demand by many different public agencies, governments, and private organizations. Each of these has the capability to establish its own differential GPS system to satisfy its local need. However, as recognized in the early 1990's, excessive redundancy could waste public resources. Therefore, a study was completed in 1994 "of all differential GPS (DGPS) services under development or deployment to determine the optimum integrated approach to providing augmented GPS services." The current DGPS programs are in accordance with the recommendations from that study. In addition, the Interagency GPS Executive Board (IGEB) considers current information on all GPS matters such as GPS augmentation and modernization. The IGEB is jointly chaired by the DOT and DoD, includes the federal agencies concerned about the GPS, and consults with the private sector. As one example, interagency cooperation, resulting in the conversion of decommissioned Air Force Ground Wave Emergency Network stations into NDGPS stations, is saving millions of dollars.

Question: Why is the government providing these services rather than the private sector? Is the government competing with the private sector?

Answer: The private sector cannot provide radionavigation services that meet all of the requirements of transportation. By law, the authority to provide radionavigation services lies solely with the Coast Guard and the Federal Aviation Administration. The safety concerns of transportation require more than just improved accuracy from its DGPS service. The service must be operated in such a way that signal availability and reliability are guaranteed. The federally provided civilian GPS services will be operated or regulated by the U.S. government. Also, the frequency bands will be protected internationally for radionavigation, thereby minimizing interference to the DGPS broadcast. The federally provided GPS services will benefit the private sector by allowing introduction of new equipment and services in a multibillion-dollar industry in which U.S. industry is the world leader.

Question: Does this endanger the privacy of citizens and enable "Big Brother" to track them?

Answer: No. The user has equipment that receives the satellite signals and calculates its location. At this point, only the user knows his or her location. For the user to send his or her location to another party, a communications system (radio transmitter) would have to be employed. The integration of GPS and a two-way communications system enables applications such as automatic vehicle location for functions such as fleet management.